SUSPENSION INSULATOR FLASHOVER UNDER HIGH IMPULSE VOLTAGES

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Some of the unpredicted flashovers on high voltage transmission lines which have been experienced during the last few years have raised questions as to the flashover performance of suspension insulators when subjected to impulse voltages considerably higher than the normal critical impulse flashover value. There has been some indication that on some of these circuits the flashovers may have occurred due to very high impulse voltages of very brief duration. These have been commonly spoken of as steep wave front surges.

The rated impulse flashover voltage of a suspension insulator string is based upon the application of a 1-1/2 by 40 microsecond wave applied to the line end of the insulator string with the tower end grounded. This so called critical impulse flashover rating is the voltage at which an insulator string may be expected to flashover on 50% of the applications under standard test conditions.

On transmission structures which are protected by ground wire, it is most likely that the lightning discharge will occur to the tower or the ground wire so that the impulse is applied to the tower end of the insulator string, and, relatively, the conductor end may be considered to be grounded. There is some question as to whether the normal critical flashover voltages which are established in the laboratory by standard test methods properly measure the performance of an insulator string when subjected to this condition.

The curve, Figure 1, shows the normal critical impulse flashover voltage of insulator strings tested under standard laboratory conditions. In this curve, arcing distance is plotted as abscissa, and it is recognized that with a good degree of accuracy the flashover voltage of conventional suspension insulators

will follow this curve irrespective of insulator spacing or surface contour, providing the spacing to diameter ratio is not too great. It has long been known that units 5-3/4" spaced by 10" diameter provide a good electrical and economic balance under most common test conditions. When, however, insulators are subjected to voltages with amplitudes considerably greater than critical impulse flashover, it is not well established whether variations in insulator spacing or surface contour will cause substantial variations in performance. There is also little information as to the influence of applying surge potentials to the tower end of the string.

This investigation, therefore, was conducted to study the effects of the following factors upon the performance of suspension insulators at critical flashover voltages and above.

1) Applying potential to the tower end of the insulator string with the line end grounded.
2) Insulator spacing.
3) Surface contour.

In observing the flashover of insulator strings the following has been noted:

1) When insulator strings are flashed over at voltages at or near the critical impulse flashover voltage, a substantial number of the arcs occur clear of the insulators. Figure 2 illustrates this this type of arc path. The time required for breakdown is usually of the order of 8 to 20 microseconds.
2) When impulses of somewhat higher magnitude are applied, the arc tends to strike from one insulator cap to the next one producing a cascade as illustrated in Figure 2. This type of arcing may occur at times of the order of 3 to 10 microseconds.
3) When the magnitude of the impulse voltage is higher resulting in very short time to flashover, arcs often will be observed hugging closely against the contours of the porcelain as illustrated in Figure 2. Such

impulses usually typify flashovers occurring in less than 3 microseconds and occur predominantly on the front of the wave.

These observations have led to the belief that possibly the actual impulse flashover voltage of an insulator at very short times is influenced to a considerable degree by the length of the cascade path following the contour of the leakage distance. If this is true, then one would expect that for any very short time to flashover, for example one microsecond, it would not be possible to draw a single curve for flashover voltage vs arcing distance for the suspension insulators. In order to show this relationship, therefore, it would be necessary to draw a curve of short time flashover vs leakage distance, or of some other factor having a value between arcing distance and leakage distance. In other words, if this be so, for the same arcing distance a string of short spaced units would contain more units, and consequently more leakage distance than a string of long spaced units, and would have a higher flashover at short times.

To study these phenomena, volt time curves were obtained on several suspension insulator strings, each composed of one particular spacing. Voltage was applied as follows:

1) Impulses of both positive and negative polarity applied to what is normally the tower end of the string with the line end grounded.
2) Impulses of both positive and negative polarity applied to the line end of the string with the tower end grounded.

No effort was made to simulate the cross arm and vertical structure of the tower. Insulators were supported from a vertical cable. In those cases where the tower end of the string was energized, the cable was suitably insulated from ground. A length of 1" O.D. pipe, approximately ten feet long, was attached to the insulator string to simulate a conductor.

These volt time curves were measured on standard 10" diameter units spaced 5-3/4", 5" and 4-3/4", each having a unit leakage distance of 11-1/2". Similar

volt time curves were also made on fog type insulators spaced 5-3/4", but having a unit leakage distance of 17" per unit. Figure 3a shows the typical 10" discs, and Figure 3b shows the fog type unit used.

Figure 4 shows a comparison of the volt time curves for strings of 5-3/4" and 5" spaced units. The line end of the strings was impulsed with a wave of positive polarity. Physical dimensions were as follows:

No. of Units	Spacing	Arcing Distance	Leakage Distance
7	5-3/4	42	80-1/2
8	5	42-1/2	92
18	5-3/4	105-1/2	207
21	5	107-1/2	241-1/2

Figure 5 shows the volt time curves of the same insulator strings having the line end impulsed with a voltage of negative polarity. Figures 6 and 7 show the volt time curves for the same insulator strings with the tower end impulsed, positive polarity and negative polarity, respectively.

As a further comparison of the influence of insulator spacing and surface contour on short time flashover, volt time curves were measured comparing:

a) Eight and 14 unit strings of 5-3/4" by 10" units.

b) Eight and 14 unit strings of 4-3/4" by 10" units.

c) Eight and 14 unit strings of 5-3/4" spaced fog type units.

These curves are shown in Figure 8. They show data positive polarity line end impulsed. Similarly, Figure 9 shows a comparison between volt time curves of eight unit strings of 5-3/4" spaced by 10" insulators, and 5-3/4" spaced fog type insulators with the tower end impulsed. Figure 10 shows volt time curves for eight unit strings, 5" spaced, which compare flashovers with the line end energized versus tower end energized.

Possible Variations in Volt Time Curves:

The measurement of flashover at very short times is subject to a number of variables. Measurement techniques have not been standardized and established to the point where the tolerance of measurement can be considered as accurate as that normally expected in critical impulse flashover voltage measurements. The variations which exist may be due to three main factors:

1) The measurement of voltage itself is subject to some error. These measurements were made with resistance voltage dividers, and it is quite probable that at very short times, the particular divider used tends to produce voltage indications on the low side.

2) The measurement of time is made from the time axis which can be very precisely determined. However, in scaling time from oscillographs definite errors may be introduced due to:

   a) The interpretation of virtual time zero

   b) The thickness of the oscillograph trace.

   It can readily be appreciated that in comparing two volt time curves the error in time could be interpreted as the difference in voltage at any particular time. If this measurement is made as a part of volt time curve where the rate of voltage rise is very steep, a very small error in measurement of the time would account for a relatively large error in the indicated voltage at that time.

3) Variables Introduced by Atmospheric Conditions: The variation of critical impulse flashover voltages with air density and humidity is well known and correction factors have been established. The corrections for such variables, which are applicable to very short time flashovers, are probably not as reliable as those commonly used at critical flashover voltage.

Recognizing the uncontrollable variables which may exist due to variations in atmospheric conditions, an attempt was made to make comparable volt time curves under the same atmospheric conditions. It was not possible to obtain some conditions exactly constant throughout the comparisons and all data recorded have been corrected following the recommendations of the American Standards Association for Measurement of Test Voltages in Dielectric Tests (C-68).

Comparison with Rod Gap.

In examining the volt time curves which have been presented, it will be noted that the flashover variations between strings of equivalent arcing distance, composed of insulators of different spacings, are quite small. The existence of the variables discussed above makes these small differences difficult to analyze. To further establish these differences, tests were made directly comparing insulator strings against a balancing rod gap. In making these tests the rod gap was connected directly in parallel with the string of insulators under test, a surge of a given amplitude applied repeatedly, and the rod gap then closed until a point was reached where flashover of the rod gap balanced with that of the insulator. Using this technique, the balancing rod gap at various overvoltages was determined on strings of 7, 9 and 11 units, 5-3/4" spaced and 4-3/4" spaced.

Figure 11 shows a plot of the balancing rod gap spacing for each of the insulator strings at over voltages up to about twice critical flashover value, yielding flashover at or near the crest. This data was taken with tower end of the string energized with negative polarity. In Figure 12 this data has been replotted in consolidated form to show a comparison on a percentage basis. The ordinate represents the ratio of the balancing rod gap length at over voltages with that at critical.

To investigate the degree of variation that might be encountered in establishing the balancing rod gap spacing, the insulator string was replaced by a fixed

rod gap having either 15, 30 or 45 inch spacing. Using the same procedure as with the insulators, the adjustable gap was moved off of the nominal setting in small increments until the flashovers of each gap no longer balanced or until dual flashover no longer occurred. Figure 13 shows the performance to be expected for various over-voltages.

Conclusions:

1) At critical flashover, all types of suspension insulators and lengths of strings will bear a flashover voltage which is very closely proportional to the dry arcing distance when the line end is impulsed. However, impulsing the tower end causes a deviation from this pattern. If the critical flashover voltages, line end energized, are taken as being 100%, then the values for the tower end energized are indicated below:

Positive Polarity - 91 - 98%

Negative Polarity - 98 -106%

2) When measurements are made of flashovers occurring at times much shorter than those at critical, the flashover voltage, tower end grounded, is nearly the same as that measured with line end grounded, but with the opposite polarity.

3) At very short times to flashover, when the arc path nearly coincides with the leakage distance contour, the flashover voltage is greater with strings employing more leakage distance per unit of dry arcing distance. Approximately 10 percent increase in leakage distance as obtained with the shorter spaced units yielded 4 to 10% increase in flashover voltage at one half microsecond. It is therefore apparent that an increase in leakage distance, as attained by either conventional insulators employing shorter spacing, or insulators employing more leakage distance by virtue of the contour, will provide higher flashovers at very short times.

4) It is recognized that voltage measurements at very short times are subject to error and that the measuring techniques used in this work may tend to produce low voltage indications when time is short. Small distortions of wave front due to corona currents may also tend to reduce the measured flashover voltages at short times. However, our interest is in relative magnitude so that these laboratory variables should not seriously affect the accuracy of the conclusions.

Bibliography

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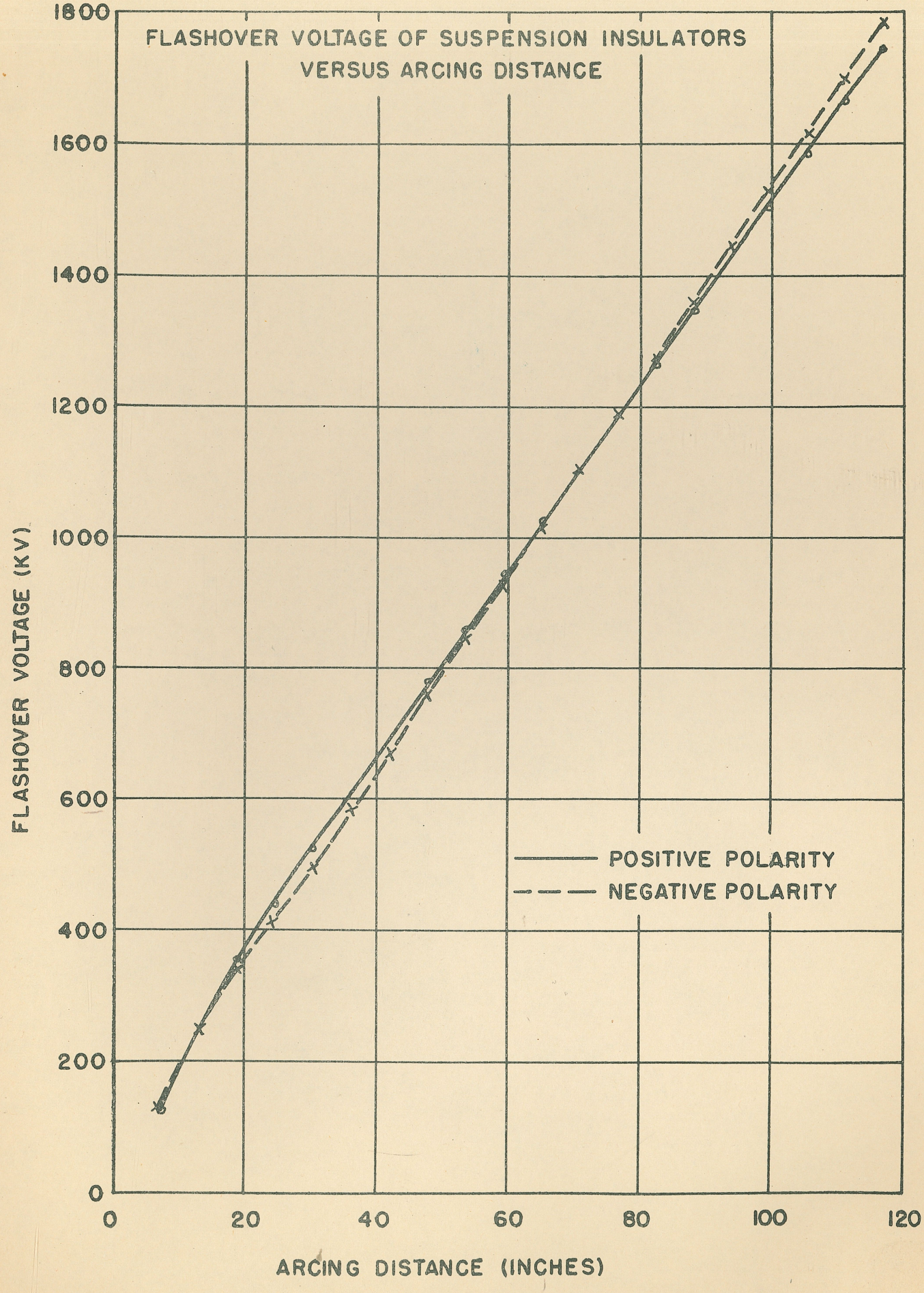

FLASHOVER VOLTAGE OF SUSPENSION INSULATORS
VERSUS ARCING DISTANCE
FLASHOVER VOLTAGE (KV)
1800
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
ARCING DISTANCE (INCHES)
POSITIVE POLARITY
NEGATIVE POLARITY

FIGURE-1

ARC PATHS OBSERVED IN TEST

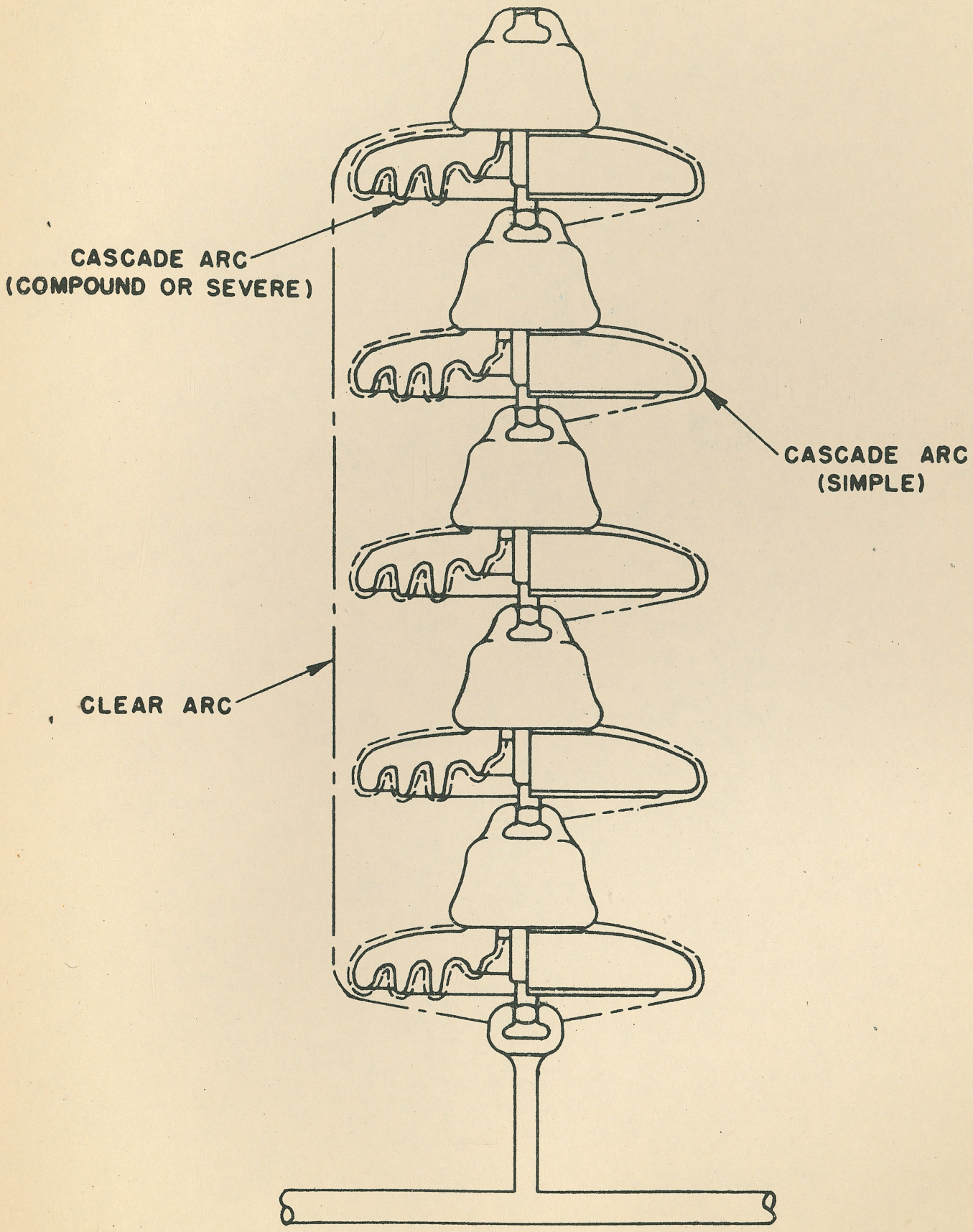
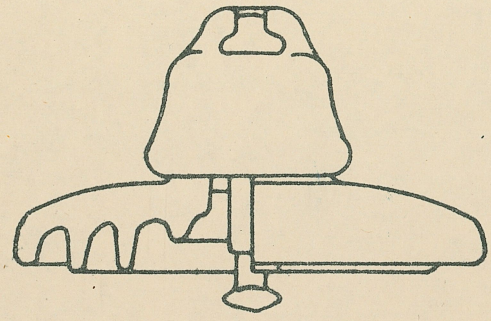


FIGURE-2

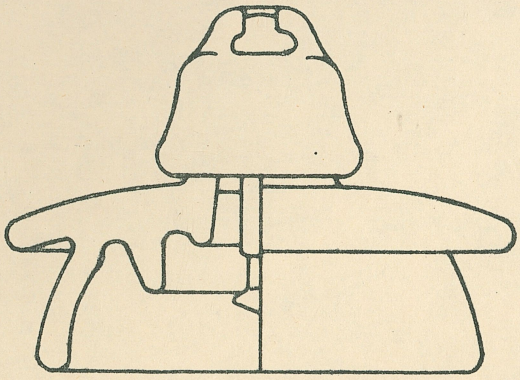
INSULATORS USED IN TEST

CONVENTIONAL SUSPENSION INSULATOR



(A)

FOG-TYPE INSULATOR



(B)

FIGURE - 3

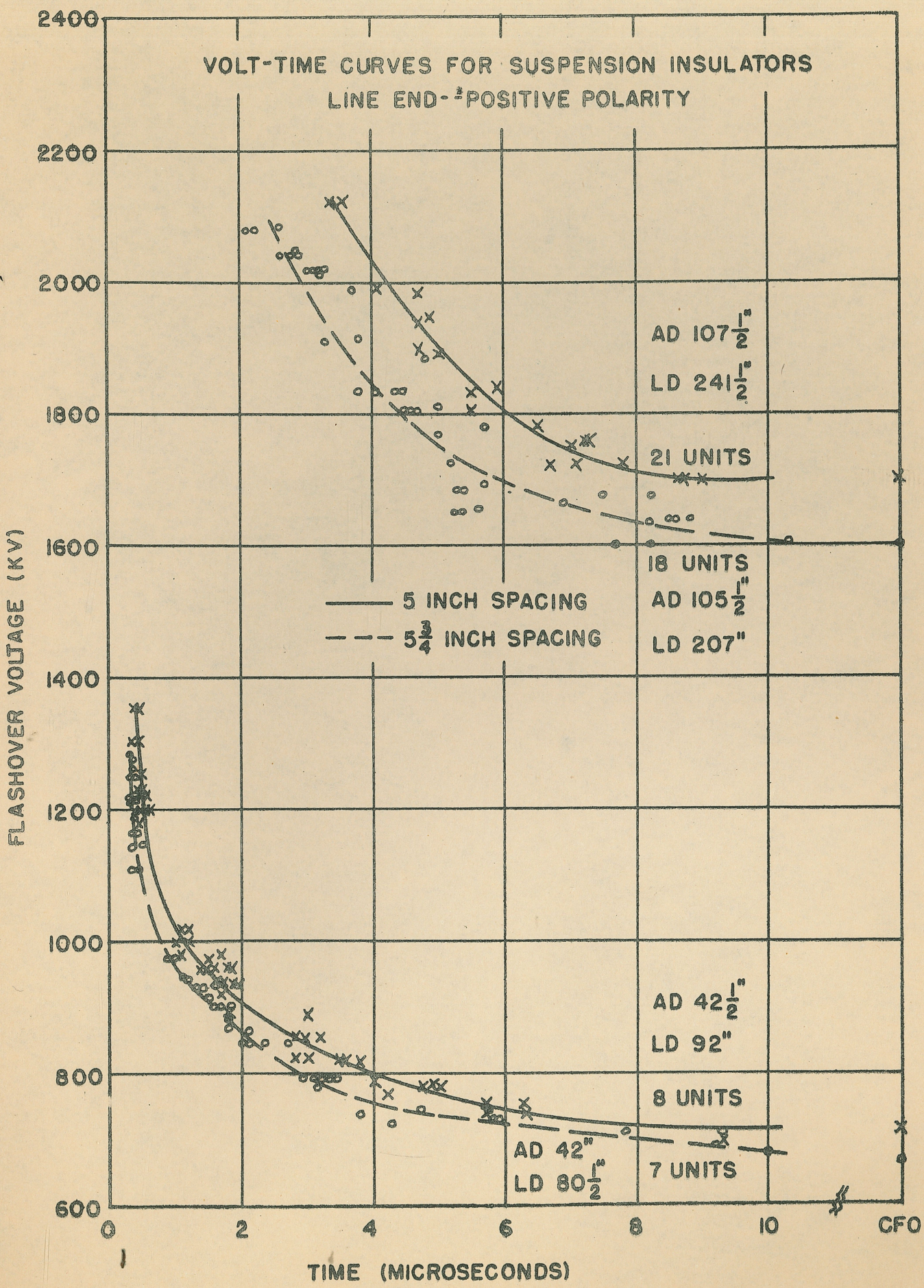

VOLT-TIME CURVES FOR SUSPENSION INSULATORS
LINE END - + POSITIVE POLARITY
FLASHOVER VOLTAGE (KV)
TIME (MICROSECONDS)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
2
4
6
8
10
CFO
AD 107 1/2"
LD 241 1/2"
21 UNITS
18 UNITS
AD 105 1/2"
LD 207"
5 INCH SPACING
5 3/4 INCH SPACING
AD 42 1/2"
LD 92"
8 UNITS
AD 42"
LD 80 1/2"
7 UNITS

FIGURE-4

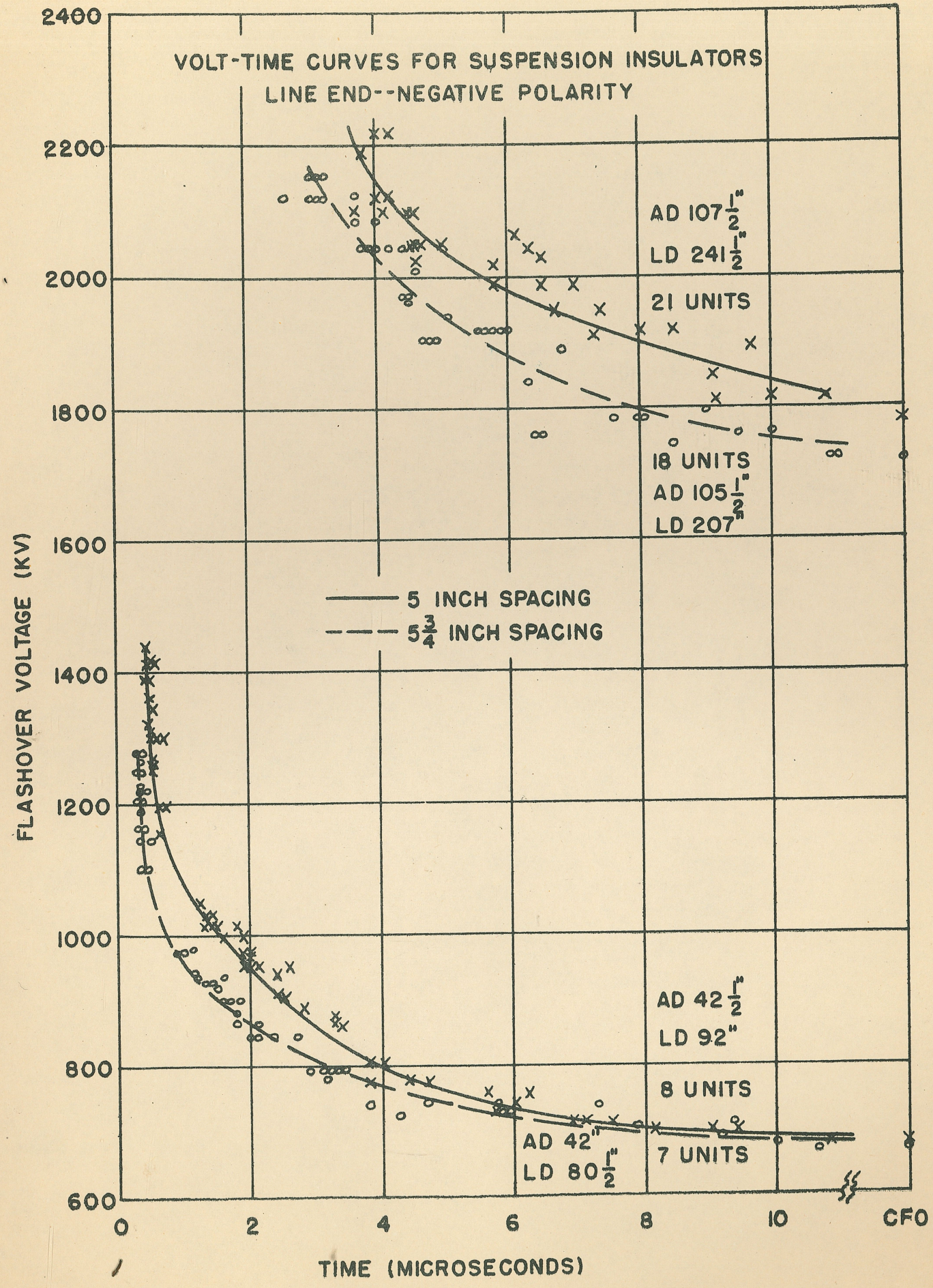

VOLT-TIME CURVES FOR SUSPENSION INSULATORS
LINE END--NEGATIVE POLARITY
2400
2200
2000
1800
1600
1400
1200
1000
800
600
FLASHOVER VOLTAGE (KV)
AD 107 1/2"
LD 241 1/2"
21 UNITS
18 UNITS
AD 105 1/2"
LD 207"
5 INCH SPACING
5 3/4 INCH SPACING
AD 42 1/2"
LD 92"
8 UNITS
AD 42"
LD 80 1/2"
7 UNITS
0
2
4
6
8
10
CFO
TIME (MICROSECONDS)

FIGURE-5

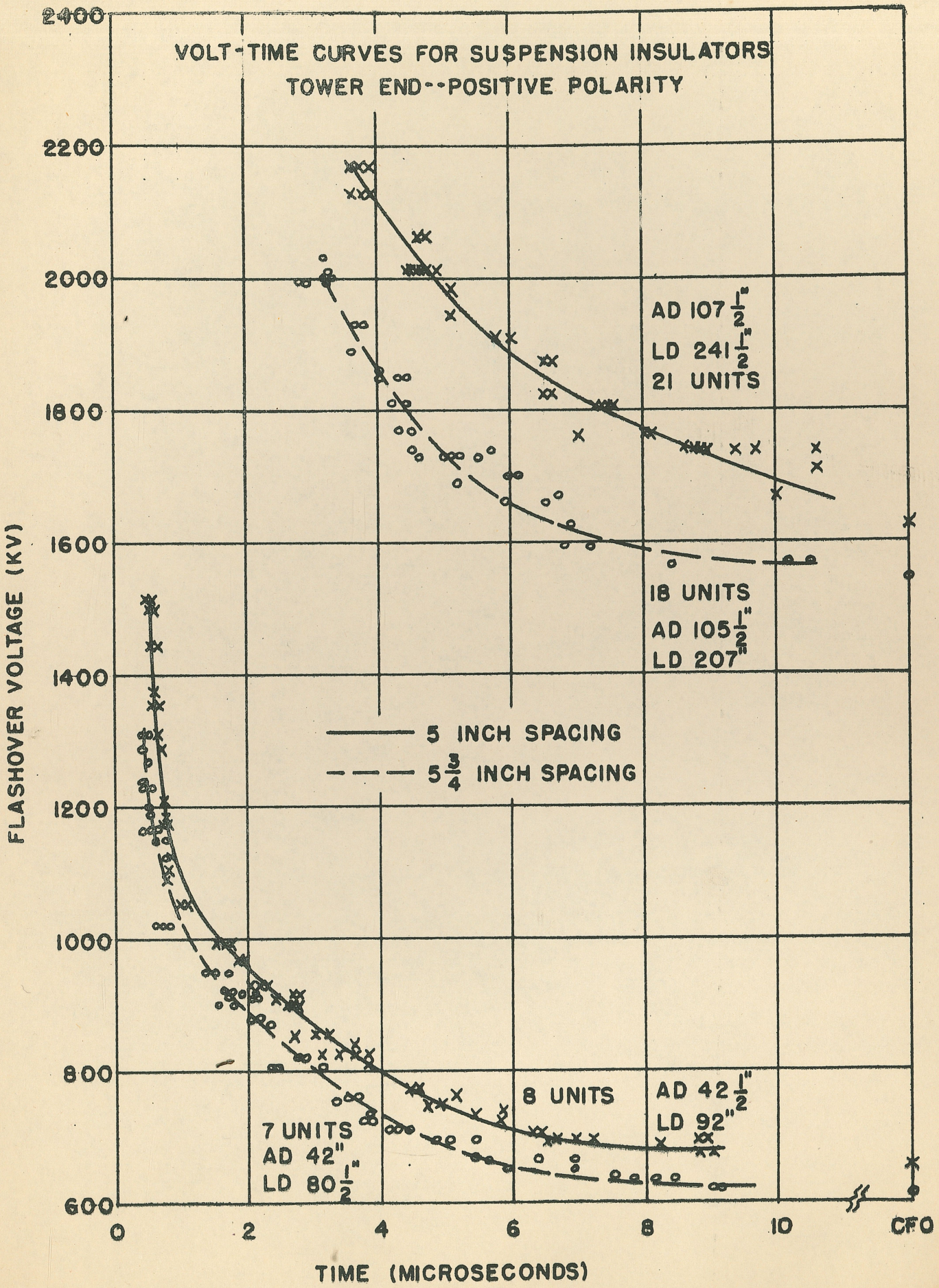

VOLT-TIME CURVES FOR SUSPENSION INSULATORS
TOWER END--POSITIVE POLARITY
FLASHOVER VOLTAGE (KV)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
2
4
6
8
10
CFO
TIME (MICROSECONDS)
AD 107 1/2"
LD 241 1/2"
21 UNITS
18 UNITS
AD 105 1/2"
LD 207"
5 INCH SPACING
5 3/4 INCH SPACING
8 UNITS
AD 42 1/2"
LD 92"
7 UNITS
AD 42"
LD 80 1/2"

FIGURE 6

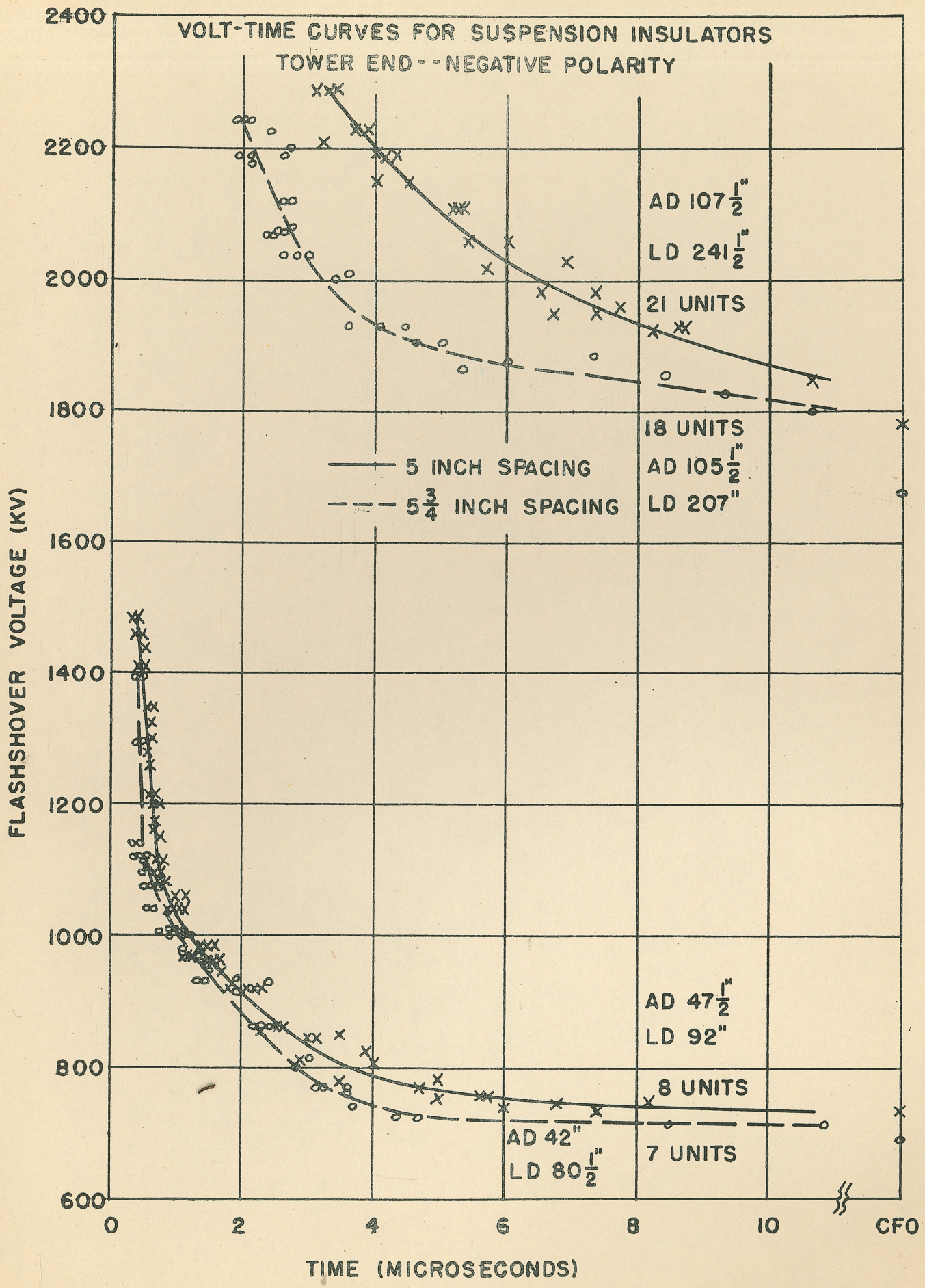

VOLT-TIME CURVES FOR SUSPENSION INSULATORS
TOWER END--NEGATIVE POLARITY
FLASHSHOVER VOLTAGE (KV)
TIME (MICROSECONDS)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
2
4
6
8
10
CFO
AD 107 1/2"
LD 241 1/2"
21 UNITS
18 UNITS
AD 105 1/2"
LD 207"
5 INCH SPACING
5 3/4 INCH SPACING
AD 47 1/2"
LD 92"
8 UNITS
AD 42"
LD 80 1/2"
7 UNITS

FIGURE-7

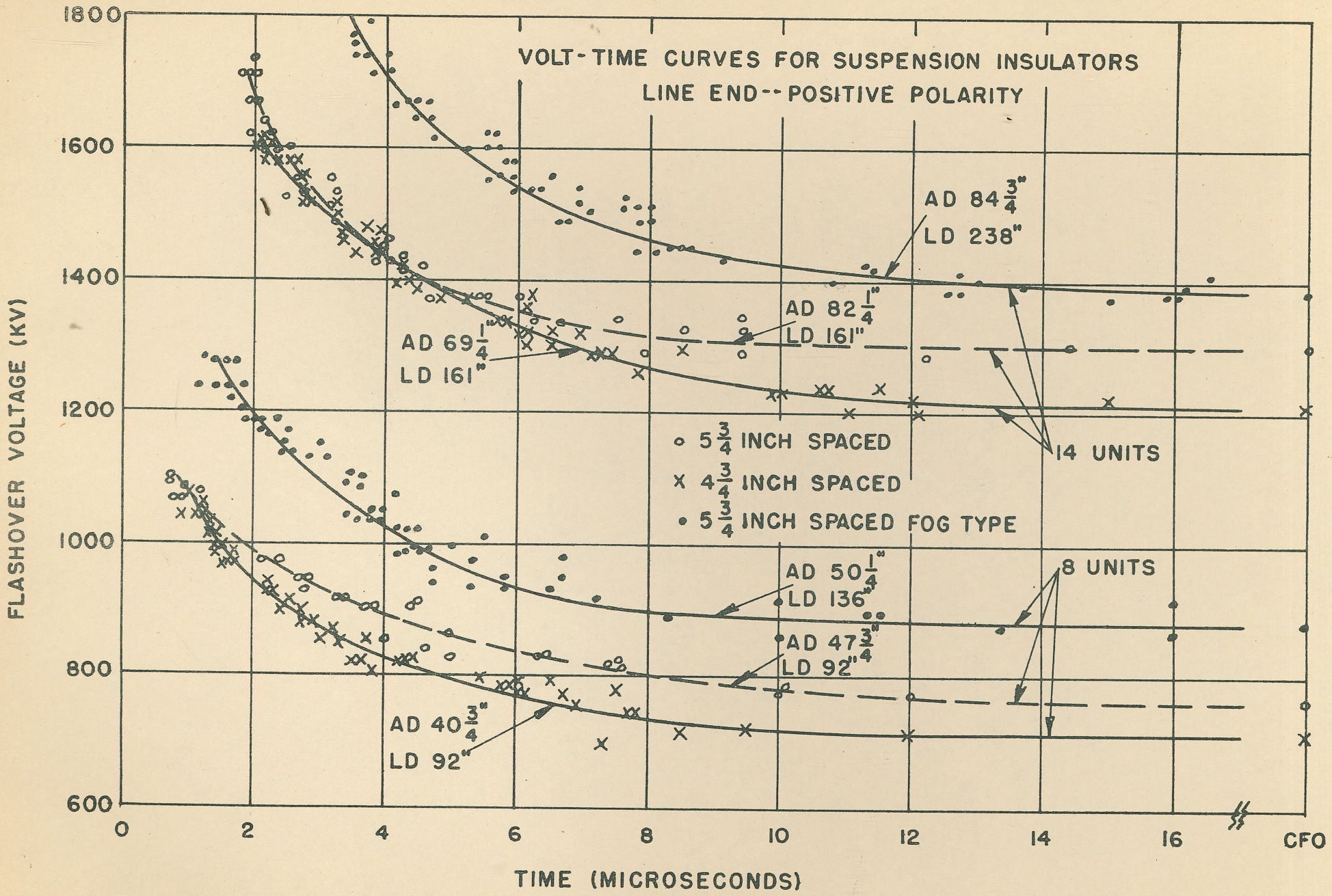

VOLT-TIME CURVES FOR SUSPENSION INSULATORS
LINE END -- POSITIVE POLARITY
AD 84 3/4"
LD 238"
AD 82 1/4"
LD 161"
AD 69 1/4"
LD 161"
14 UNITS
5 3/4 INCH SPACED
4 3/4 INCH SPACED
5 3/4 INCH SPACED FOG TYPE
AD 50 1/4"
LD 136"
8 UNITS
AD 47 3/4"
LD 92"
AD 40 3/4"
LD 92"
FLASHOVER VOLTAGE (KV)
1800
1600
1400
1200
1000
800
600
0
2
4
6
8
10
12
14
16
CFO
TIME (MICROSECONDS)

FIGURE-8